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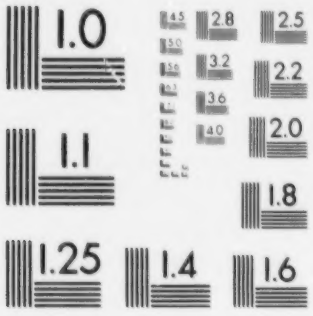

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REPORT

TO

DEPT. OF SUPPLY & SERVICES

ON THE

ECONOMICS OF COOL STORAGE

FOR

BELL NORTHERN RESEARCH LAB 5
Ottawa, Ontario

AND A

COMPARISON OF CHILLED WATER

WITH

THREE TYPES OF ICE STORAGE MODULES

June 1989

43pp

MICROMEDIA

TABLE OF CONTENTS

I	PURPOSE FOR STUDY	1
II	DESCRIPTION OF THE PREMISES	2
	Existing	2
	Future	2
III	MAXIMUM COOLING PROFILES	3
	Existing Premises	3
	Future Premises	3
	Winter Cooling Loads	4
IV	POTENTIAL FOR COOL STORAGE	5
	General Economics	5
	Substitute for New Chillers	5
	Ontario Hydro Incentive	5
V	POTENTIAL FOR ICE STORAGE	6
	General	6
	Description of Brine Coil System	6
	Description of Ice-on-Coil System	7
	Description of the Refrigerated Tube System	8
VI	POTENTIAL FOR CHILLED WATER STORAGE	9
	Description of Tanks	9
	Use of Existing Chiller Capacity	9
	Partial Water Storage with New Chillers	12
VII	INITIAL COST OF STORAGE ALTERNATIVES	13
VIII	ENERGY REQUIREMENTS OF STORAGE ALTERNATIVES	14
IX	ECONOMIC ANALYSIS	15
X	CONCLUSIONS	16
XI	RECOMMENDATIONS	17

FIGURES

Figure #1	Bell Northern Research Laboratories
Figure #2	Piping Schematic for Existing Plant
Figure #3	Computer Printout of Cooling Load on 4 Aug/88
Figure #4	Max.Cooling Load 4 Aug/88 Admin.& Labs 1,2,3
Figure #5	Heaviest Winter Cooling Load
Figure #6	Maximum Cooling Profiles Lab 4 & Lab 5
Figure #7	Typical Strata-Therm Chilled Water Thermal Energy Storage Installation

Figure #8 Available Off-Peak Cooling Capacity with Existing Chillers
Figure #9 Bell Northern Central PC Graph 89/03/07
Figure #10 Relationship Between Lab 5 Max.Cooling Load, Available Cooling Capacity and Storage
Figure #11 New Circuit Diagram for Lab 5
Figure #12 Level Load Cooling Diagram BNR Lab 5
Figure #13 Brine Coil Circuitry
Figure #14 Ice on Coil Circuitry
Figure #15 Circuit Diagram for Refrigerated Tube
Figure #16 Chilled Water Storage for Lab 5
Figure #17 Initial Cost Comparison
Figure #18 kW Input to Cooling Plant for Various Storage Schemes
Figure #19 Development of an Approximate Annual Cost of Cooling
Figure #20 Electric Demand Profiles for Lab 5 Cooling for Max. Summer Day
Figure #21 Future Maximum Electric Demand Profiles
Figure #22 Comparison of Systems after Five Years of Energy Cost

I PURPOSE FOR STUDY

The escalating cost of new electric generation has inspired investigation of concepts for levelling demand and improving electric load factors.

The outstanding candidate for load levelling has been cool storage. With some electric utilities, mechanical cooling has been responsible for over 50% of peak summer demand.

Bell Northern Research Laboratories is a prime candidate for cool storage because cooling loads for computer rooms and process continue on a year round basis. Consequently, electric demand shaving could be practised in every month.

This study will examine the economics of cool storage but it will have a further rationale by comparing the viability of several types of cool storage hardware. For many years chilled water storage was the only concept which could be managed with centrifugal refrigeration capable of avoiding the high cost of operators in constant attendance. Today, however, the centrifugal chiller has been adapted for chilling glycol to temperatures which can generate ice. Thus, the choice of storage media has expanded to include ice manufactured with several types of hardware.

In summary, the study has been commissioned to provide an update on cool storage economics with all of the concepts currently available to Canadian purchasers. Bell Northern Research Laboratories will be used as a candidate for the study because it plans future expansion and is thus a good storage prospect.

II DESCRIPTION OF THE PREMISES

Existing

The existing complex consists of four buildings as shown in Figure 1. The total area of 60,000 m^2 comprises an administration block plus laboratories #1, #2 and #3. The largest lab, #3, has an area of 32,600 m^2.

Future

Future expansion involves a new building, laboratory #4. This will be a two storey structure of 5800 m^2 located where shown. It involves a 1500 m^2 clean room and other processes similar to lab #1. Contracts are already let for the construction of lab #4.

Further expansion is expected to take place with several additional laboratory buildings. One, of 56,000 m^2, which will be known as lab #5, is shown in four shaded areas on Figure 1. Its function will resemble that of lab #3.

III MAXIMUM COOLING PROFILES

Existing Premises

Chillers for the existing complex include two Carrier 460 tons units plus two Trane units, one of 650 tons and another of 500 tons with a heat recovery capability. Total is 2070 tons.

These chillers are connected to various chilled water coils through primary-secondary pumping loops. Water is chilled to 5.5°C (42F) in the primary loop and distributed to the coils at 6.8°C (44.2F) in the secondary loop. See Figure 2.

The maximum summer cooling load occurred on 4 August 1988. This was tabulated on a computer printout shown as Figure 3. It is also shown graphically on Figure 4.

From this information, it is apparent that cooling loads in the administration building and lab #2 are fairly constant while the profiles in labs #1 and #3 contain sharp peaks at 11 a.m. and 1 p.m. respectively. The peak in lab #3 relates to the cafeteria and occurs on other days. The peak on lab #1 is not so consistent and is of unknown origin. Notwithstanding, these profiles do represent the maximum with the existing plant and will be used to project loads on future lab extensions.

Heating loads are handled substantially by the heat recovery chiller. With continuous operation, this unit has no need for heating storage to time cycle heating output.

Future Premises

Chillers are on order for lab #4. They include three 750 ton units and one 230 ton unit. One of the 750 ton units has heat recovery potential. Another 750 ton unit is used for standby.

These chillers provide for a 1730 ton cooling load which includes some capacity for increased loads in labs #1 and #3 which may develop in future years. They will be located in the existing chiller room.

Future chillers for lab #5, and thereafter, are expected to be housed in a proposed central energy centre located where shown in Figure 1.

Cooling profiles for lab #4 are expected to resemble lab #1 while the profile for lab #5 will follow lab #3. These projected profiles are shown in Figure 6. The curve for lab #4 borrows its shape from the lab #1 profile shown in Figure 3. Its capacity derives from the proration of 1730 tons for lab #4 over the 525 ton peak for lab #1. The curve for lab #5 is congruent with the profile for lab #3 shown in Figure 4. Its capacity is prorated by the 56,000 m^2 area of lab #5 over the 32,600m^2 area of lab #3.

These approximations will need refinement when more accurate data is available. In the meantime, the projections will enable some analysis for the thermal storage

opportunity.

Winter Cooling Loads

The maximum winter cooling load at present is 504 tons as shown on Figure 5. Based on a future doubling of area, a winter load of 1000 tons may be expected eventually. The year round cooling requirement augurs well for storage since winter loads of this size could be handled without on peak chiller operation.

IV POTENTIAL FOR COOL STORAGE

General Economics

Chilled water storage acts to reduce the cost of electric demand. In some cases this is the only benefit with which to offset the initial cost of the storage itself, its interface with the system and the cost of a nominal increase in kilowatt hours.

Experience has shown that, even with electric demand costing $10/kW/month there is an inadequate saving to compensate for premium investment in storage.

In this and in other cases there must be an offsetting first cost.

Substitute for New Chillers

Where a cooling plant is being expanded, the addition of storage can often eliminate the need for supplementary refrigeration. It will be shown that, at Bell Northern Research, the chillers, already purchased for lab #4, can operate with storage to avoid the purchase of 1200 tons of chiller capacity for lab #5.

Ontario Hydro Incentive

Ontario Hydro has declared an interest in subsidizing any concept which will avoid the cost of new electric generation. The value of the subsidy has been set at $200 per avoided kilowatt of demand.

It will be shown that a storage system can be used to avoid up to 900 kW in the summer months and up to 500 kW in winter months (when the avoidance is worth even more than $200/kW to Ontario Hydro.)

The combination of offset in the cost of new chillers for the future lab #5 and the subsidy from Ontario Hydro, together, can make a good case for cool storage.

V POTENTIAL FOR ICE STORAGE

General

The Bell Northern Research Laboratory complex may be a poor candidate for ice storage. While chilled water storage can take advantage of the spare capacity of existing chillers, none of the eight units are presently able to chill brine to the lower temperatures suitable for ice making. Although it might be possible to modify some of the chillers for brine cooling, the initial cost would be a serious handicap to ice making economics. If the new 750 ton units had been ordered for ice making duty, they could have been provided at equal first cost. The units would then have had a capacity of 550 tons with 22F (-5 1/2°C) brine and 80F (26 1/2°C) condensing water. The lower capacity for ice making would be a further offset in favour of chilled water storage.

Notwithstanding the inferior economics, in this instance, ice storage will be reviewed on the basis that the cooling plant for Lab #5 and future labs will not benefit from the interconnection with existing chillers and will stand alone for Lab #5.

The best economics for any type of storage are usually obtained when the chillers serve the maximum load by operating at full capacity for the whole 24 hours in the day. This is illustrated in Figure 12.

By operating at 771 tons capacity, a demand reduction of (1005 - 771) or 234 tons can be accomplished with only 850 ton hours of storage.

Chillers would have to be purchased to manage 771 tons with 22F (-5 1/2°C) brine and 80F (26 1/2°C) condensing water. Between the hours of 10 a.m. to 7 p.m. no ice making is required. During this interval the chillers could produce brine as high as 45F (7°C) while allowing the ice tank to cool the balance of the range. This would allow the chillers to operate at about 75% of ice making energy for part of the day.

Description of Brine Coil System

The brine coil ice module which is now available in Canada is made by Calmac Manufacturing in Englewood, N.J. and marketed in Canada by Trane. It consists of coils of polyethylene tubing immersed in water filled, plastic containers, each measuring about 2 m in diameter by 2 m in height. Glycol can be pumped through the tubing at a maximum temperature of 22F (-5 1/2°C) to freeze the water in the container. During the discharge cycle, warmer glycol is cooled to useful temperature by the melting of the ice. Each module has a cooling capacity of 190 ton hours if the enthalpy between solid ice and water at 50F (10°C) is included. As the ice melts away from the glycol tubing, however, the melted water acts as insulation and elevates the leaving temperature of the glycol. The net rating of the module is therefore a function of the maximum leaving temperature. At 36F (2 1/2°C) leaving glycol, 50% of the nominal ton hours are available. At 38F (3 1/2°C) glycol, some 70% is available, allowing the load to be served with

fewer modules.

In this case some additional piping and control valves have been included to allow the ice modules to be discharged either before or after the chiller. In this way, up to 175 ton hours can be made useful in each module and the number of modules can be reduced to six. Figure 13 shows how the modules can be discharged downstream of the chiller in the morning until they have been 70% used. When the glycol leaving the ice bank reaches 38F, the circuit can be reversed so that the ice cools the high end of the range and the chiller maintains the appropriate final temperature.

As an upstream device, the chillers may be able to accomplish 771 tons with as little as 70% of ice making energy. In the downstream configuration the chillers may require 75% of night time energy.

Diverting valves V_1, V_2 and V_3 would be used to reverse the lead-lag arrangement. They would have slow action so that the chiller would be able to accept its new discharge temperature without surging. Valve V_4 would blend the glycol temperature to the scheduled delivery temperature for the Lab #5 cooling coils. This would be particularly important at night when the glycol leaving the ice modules may be cold enough to ice up the cooling coils.

The circuit shown in Figure 13 has been prepared without a heat exchanger, assuming that glycol will be circulated to all the cooling coils. This offers a more economic solution than a glycol to water heat exchanger despite the fact that the piping and coils may have to be fractionally larger and the circuits filled with glycol. The saving will be enhanced if some of the coils must revert to glycol in any case for winter operation with a high outside air ratio.

Description of Ice-on-Coil System

The ice-on-coil module, presently made in Canada, is sold by Baltimore Air Coils Ltd. It consists of a steel pipe coil in a water container with an air bubbler to facilitate the even building and melting of the ice. Modules up to 1200 ton hours are made in a single unit. Installations above 5000 ton hours are often arranged so that the pipe coils are installed in buried concrete vaults.

The ice-on-coil unit has a fairly flat discharge temperature profile and can be arranged in a position downstream of the chiller as shown in Figure 14.

Since the ice module contains water at atmospheric pressure and, since the water in the tank has a high oxygen content caused by the bubbler, a heat exchanger has been added to interface with the cooling coil circuit for Lab #5.

The manufacturer has reviewed the cooling load profile and offered the circuitry shown in Figure 14 as optimum. The use of a third glycol chiller to generate the necessary 850 ton hours of ice storage allowed the principal chillers to operate with chilled water. This reduced first cost and provided a better energy quotient.

The circuit also avoided duplication of chiller and cooling coil pumps although additional pumps are required for the storage input.

Description of the Refrigerated Tube System

This Canadian concept, developed by Sunwell, generates small ice crystals in a 5% glycol solution by passing the solution through a tube surrounded by 16F (-9•C) refrigerant. The tube is not developed as yet to use a glycol solution which could be refrigerated with a centrifugal chiller. The 106 ton refrigeration cycle shown on Figure 15 incorporates either a screw type or a reciprocating chiller with refrigerant 12 or 22.

The system would incorporate an 18000 gallon (68 m^3) insulated tank to retain the water and ice slurry mix. This tank would provide a 32F (0•C) glycol solution to the lab #5 cooling coils enabling the circulation rate to be reduced from 1210 GPM (4.5 m^3/m) to 930 GPM (3.5 m^3/m).

The lower rate of flow can be of some help in reducing pipe size and airflow rates.

The ice generator will operate continuously on the maximum day. This enables the storage to regenerate 850 ton hours while reducing the size of the principal chillers from 385 to 335 tons. This mode of operation entailed the highest cost of energy, however.

VI POTENTIAL FOR CHILLED WATER STORAGE

Description of Tanks

If chilled water storage is used, the tanks must be surface mounted because of rock underlay. They can be located alongside the future central energy centre where shown on Figure 1. For aesthetic reasons the height should be limited to 12 m.

At present, the cheapest tanks designed for surface mounting are fabricated in steel. An example of a tank made specifically for chilled water storage is shown in Figure 7.

Specifications call for a concrete mounting ring, 2 inches of sprayed insulation with weather resistant finish and internal distribution headers designed to facilitate temperature stratification within the tank.

Use of Existing Chiller Capacity

There is a useful coincidence between the 18,500 ton hours of cooling which may be required to satisfy the maximum load for Lab #5 and the 17,400 ton hours spare, off peak, capacity available from chillers in the existing buildings and Lab #4. The surplus cooling capacity is displayed on Figure 8.

Although the typical electric demand for the existing complex is fairly constant as shown in Figure 9, there is 500 kW available below peak between 7 a.m. and 9 a.m. and 300 kW available below peak between 4 p.m. and 11 p.m.

Figure 10 has been configured to show the maximum cooling profile of Lab #5 alongside the spare chiller capacity which can be operated below the peak. The full storage shortfall of 1100 tons hours can be restored by taking advantage of the dip in the electric demand profile prior to 9 a.m. and after 4 p.m. These dips might be expected to double in size with the addition of Labs #4 and #5, so that 1000 kW and 600 kW, respectively, could be used for water chilling before 9 a.m. and after 4 p.m. Figure 10 shows how 1000 tons, tapering to zero tons, could be operated from 7 a.m. to 9 a.m. and 600 tons could be operated after 6 p.m., with a taper to zero at 4 p.m.

In summary, the existing chillers could generate as much as 22,000 ton hours without any increase in electric demand for water chilling in Lab #5. If the chillers operate to the maximum extent shown, full storage could be achieved with as little as 9600 ton hours of storage.

It will be assumed that the storage can be charged with 4 1/2°C (40F) water and that the chilled water coils for labs #4 and #5 will be designed to return water at 15 1/2°C (60F) during maximum cooling conditions. New and existing chillers should have no difficulty in generating 4 1/2°C (40F) water. The 15 1/2°C (60F) return water temperature can be justified on the basis that the savings in pump, pipe and insulation size and the savings in pump energy, together, justify the

required increase in surface area for the cooling coils. There need be no increase in fan energy for "heavier" cooling coils providing the extra surface is provided in face area rather than rows deep. It should also be suggested that a 15 1/2•C (60F) return water temperature from computer air handlers should require no extra coil surface. In order to avoid parasitic electric rehumidification energy, the water entering the computer A.H.U. coils should not be less than 12.8•C (55F). This would predicate a leaving water temperature of not less than 15.5•C (60F).

The chilled water storage can now be sized on the basis of an 11.1•C (20F) chilled water range which will require

$$\frac{12{,}000 \text{ Btu/ton hr}}{2200 \text{ lbs/m}^3 \times 20\text{F T} \times 0.9 \text{ effy.}} \text{ or } 0.3 \text{ m}^3\text{/ton hour}$$

Thus the minimum capacity for storage on Lab #5 will be 0.3 x 9600 or 2880 m^3.

Circuit Diagram

Operating Lab #5 from the existing chiller plant will require a new pair of mains to interconnect the existing chiller plant with the storage tank farm which will be adjacent to the new energy plant.

This can be accomplished with a pair of 350 mm diameter pipes, capable of carrying the full 2500 ton regenerating capacity for Lab #5 storage. Such an interconnect would also be valuable in the future as a back up between plants. The new lines would be capable of moving chilled water in either direction.

A simple circuit to connect Lab #5 storage with the existing chiller plant is shown in Figure 11. The location of the interconnecting mains is shown in Figure 1.

There is concern for the spare capacity of the present chillers since all four were required to operate during the maximum day on 4 August 1988. The likelihood however, is that three chillers could have carried the load if the chilled water range had been greater. At the peak time the range was still short of 10F (5 1/2°C) and the meters revealed that the plant was 520 tons short of rated capacity.

The problem in being unable to load the chillers for lack of range will be overcome if the cooling coils for Lab #5 are designed for a 20F (11°C) range. Then, at night, when the chillers are reused to recharge the storage, the return water will be a 50/50 blend of 50F (10°C) water from coils in Labs #1 to #4 and 60F (15 1/2°C) water from the storage tank. The range across the chillers will then become a more satisfactory 55F to 40F (12 1/2°C to 4 1/2°C) which will allow them to operate at full capacity.

There is a strong argument for using the 20F (11°C) chilled water range for all future construction. When this range is met, in most installations, the additional cost of cooling coil surface is overcome by the savings in pump and pipe size and pipe insulation. Other savings, of longer duration, include pump energy and fan energy. Fan energy will be saved if the extra coil surface is added in face area rather than rows deep.

With a 20F (11°C) range, the water required for one ton hour is

$$\frac{12{,}000 \text{ Btu/ton}}{8.33 \text{ lb/gal} \times 20 \times 0.9 \text{ effy.}}$$ or 80 gallons ($0.3 m^3$)

For 9600 ton hours of storage, as shown on Figure 10, the tanks should be sized for 9600 x 80 or 768,000 gallons. ($2880 m^3$)

The cost of extra capacity is less than 50¢/gallon at this size, so 1,000,000 gallon ($3{,}770 m^3$) capacity will be recommended in either one or two vertical cylinders. For a 35 foot (11 m) depth of water, and 40 ft. (12 1/2 m) profile, the tanks should be either one at 70 ft (21 m) diameter or two at 50 ft. (15 m) diameter. To keep the future tanks from becoming too numerous and for economy, one tank is recommended.

Partial Water Storage with New Chillers

When the chilled water range is selected for 18F (10•C) or higher, water storage tends to be cheaper than ice storage for cooling loads exceeding 500 tons. This turned out to be the case in this instance, although the cheaper above-grade storage tank helped to improve the comparison.

The water installation is shown on Figure 16. Energy savings normally attributable to chilled water are reduced in this case by direct static head pumping from the tank and by having to maintain a 38F (2 1/2•C) discharge 24 hours a day during maximum load.

The water tank would be similar to the one shown in Figure 7. It would be equipped with top and bottom distribution piping, for stratified storage, and exterior insulation.

VIII ENERGY REQUIREMENTS OF STORAGE ALTERNATIVES

This report does not provide the scope to do a serious energy analysis. However, chiller and pump energy were assessed using the circuit diagrams and typical operating conditions. From this, Figure 18 was developed to compare electric demand for the conventional and five storage alternatives.

Figure 19 was developed from Figure 18 by assuming that there would be 22 equivalent full load days in each month and seven equivalent full load months in each year.

Ontario Hydro has asked for an hour by hour comparison of electric demand with and without storage for maximum summer and maximum winter cooling loads. The maximum summer projection is shown for Lab #5 cooling on Figure 20. A projection for the impact of storage on the overall building demand is shown on Figure 21.

The winter cooling load is less well known although the maximum load revealed by computer printouts to date is 506 tons as shown on Figure 5. Lacking a winter demand profile, it is not possible to plot the consequences of using 850 ton hours of storage. However, the large storage system, proposed for use with existing chillers, would continue to act as a full storage, stripping all cooling demand except the 50 kW required by the Lab #5 cooling coil pumps.

IX ECONOMIC ANALYSIS

Some idea of how conventional cooling would compare with the storage alternatives is shown in Figure 22. Here the savings in electricity for the storage systems for five years are deducted from the first cost.

The result shows the two chilled water storage systems to have financial appeal.

If the full storage alternative were put in with the minimum storage tank, and if the interconnection between plants is considered desirable in its own right, this scheme would become the lowest first cost overall even without the excellent savings it can demonstrate.

X CONCLUSIONS

1. This study has determined that an opportunity exists to provide a cost effective cool storage system for the proposed Lab #5.

2. The leading candidate for consideration involves the use of likely spare capacity among the existing chillers to regenerate a full storage chilled water tank alongside the Lab #5 site. A pair of 350 mm interconnection pipes will be required for this purpose. This interface would be valuable, in any case, to provide breakdown protection between existing and future chiller plants.

3. The smallest tank to provide full storage for Lab #5 would be 770,000 gallons (2900 m^3). A tank of 1,000,000 gallons (4140 m^3), however, is recommended. The larger tank, which can be provided for as little as an extra $100,000, can offer demand stripping on Lab #4 as well as future capacity for Labs #6, #7 and #8.

4. If the existing spare chiller capacity is not used, the only storage systems which would be cost effective are level load partial storage systems. Of these, the chilled water concept, with a 70,000 gallon (265 m^3) tank, appears viable within a 3.75 year payout. The ice storage systems, as expected for this size of plant, are less economic with simple payout periods as follows:-

Brine Coil	9.3 years
Ice on Coil	8.3 years
Refrigerated Tube	21.0 years

As noted earlier, the refrigerated tube system can be configured to provide a 32F (0°C) cooland to the Lab #5 cooling coils. This might enable reductions in piping and air handling sizes sufficient to allow it to compare favourable with the other ice systems.

5. All systems have been reviewed on the basis of ability to provide a 38F (3 1/2°C) coolant. The advantages of such a low temperature reside in the potential for reducing air handling capacity and providing better control of relative humidity at partial cooling loads. The computer areas would be separately controlled at specific relative humidities, of course.

6. Systems were selected on the basis of exactly meeting the presumed cooling load for Lab #5. In practice, some spare capacity should be provided for both the chilling plant and storage.

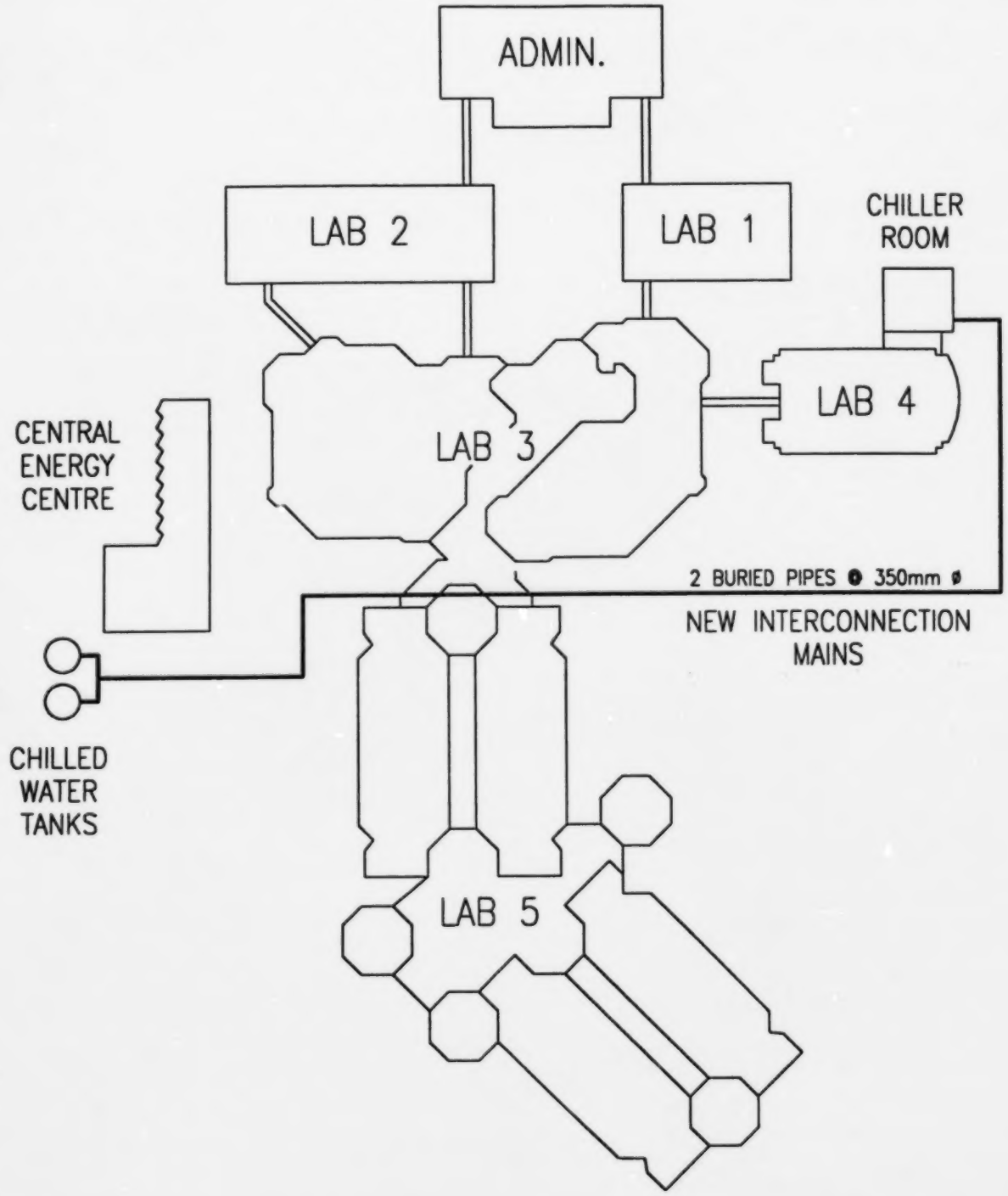
7. Lab #5 has such a flat cooling profile that it is not a prime candidate for cool storage. Only the 1 p.m. peak in the curve and the size of the Lab #5 system allow consideration of the partial storage systems.

XI RECOMMENDATIONS

1. Consider the advantage of the chiller plant interconnection and ensure that allowance is made for this in site preparation for future construction.

2. Note that the assumptions of cooling loads for Labs #4 and #5 are tentative and, before a serious storage design is undertaken, should be checked and refined by the designers.

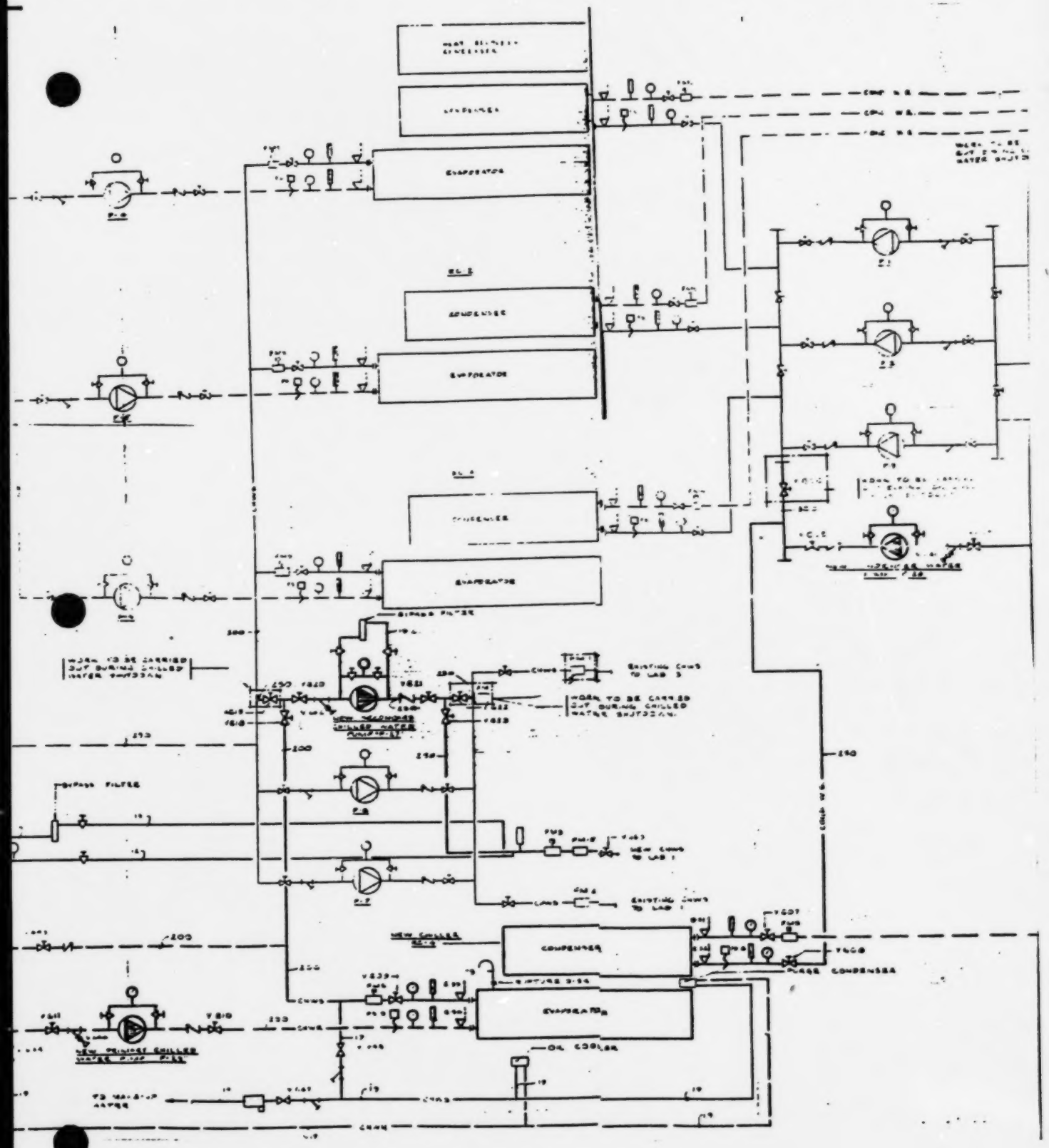
3. Suitable safety factors and capacity margins could be added at that time.



APPROX. SCALE: 150'=1"

BELL NORTHERN RESEARCH LABORATORIES

FIGURE 1



PIPING SCHEMATIC FOR EXISTING PLANT

FIGURE 2

Figure #3

SYSTEM INFORMATION - TREND LOG

TREND LOG : 1

DGN DAY 5 THU 4 AUG 1988 11:02 PAGE : 0001

			LEVEL II	LEVEL III	ENG	COL	SYS	LEVEL I	LEVEL II	LEVEL III
1	H	CH	CHILLER BLDG CHW CHW CIRCUIT	EM6 ADM FLOWMTR	LPS	7	H	CH CHILLER BLDG	CHW CHW CIRCUIT	L2A LB2-ADM RET
2	H	CH	CHILLER BLDG CHW CHW CIRCUIT	EM5 LAB1 FLOWMTR	LPS	8	H	CH CHILLER BLDG	CHW CHW CIRCUIT	L1R LAB1 CHW RET
4	H	CH	CHILLER BLDG CHW CHW CIRCUIT	EM2 LAB2-ADM FLO	LPS	9	H	LAB3 LAB #3	WST WEATHER STN	OAT OUT AIR TEMP
5	H	CH	CHILLER BLDG CHW CHW CIRCUIT	EM1 LAB3 CHW FLO	LPS	10	H	LAB3 LAB #3	WST WEATHER STN	OAH OUT AIR HUM
6	H	CH	CHILLER BLDG CHW CHW CIRCUIT	L1S LAB1&3 CWSUP	DEGC	11	H	CH CHILLER BLDG	MIS CELLANEOUS	OAT OUTDOOR AIR
				L3R LAB3 CW RET	DEGC	12				

TIME	1 LPS	2 LPS	3 LPS	4 LPS	5 DEGC	6 DEGC	7 DEGC	8 DEGC	9 DEGC	10 %RH	11 DEGC	12
8/03												
00:02	6.80	35.10	59.30	80.60	6.80	12.90	12.10	10.80	23.10	80.00	20.80	
01:02	6.80	45.50	54.80	71.40	6.80	12.90	11.50	11.80	23.10	80.00	21.20	
02:02	6.80	41.40	56.90	71.30	6.80	12.90	11.30	11.80	22.60	80.00	21.80	
03:02	6.80	41.40	53.20	72.20	6.80	12.40	11.50	11.80	23.10	80.00	21.80	
04:02	6.80	39.30	57.20	72.20	6.80	12.90	11.50	12.80	23.10	80.00	22.30	
05:02	6.80	39.30	54.30	72.70	6.80	12.90	11.70	12.80	22.60	80.00	22.80	
06:02	6.80	39.40	54.30	72.30	6.80	12.90	11.50	12.80	22.60	80.00	22.80	
07:02	6.80	42.70	53.70	71.70	6.80	12.90	11.50	12.80	23.10	80.00	23.30	
08:02	6.80	58.30	54.30	73.50	7.30	13.90	11.90	12.80	25.60	80.00	24.80	
09:02	6.80	60.40	55.70	75.60	7.30	13.40	11.90	12.80	28.10	75.00	26.30	
10:02	6.80	70.80	53.50	75.50	7.30	13.40	12.10	12.80	28.60	75.00	26.80	
11:02	6.80	74.00	57.00	79.40	7.30	13.90	12.30	12.80	30.60	70.00	27.80	
12:02	6.80	81.20	57.40	80.90	7.30	13.90	12.50	12.80	33.10	65.00	30.30	
13:02	6.80	80.90	56.30	88.50	7.30	14.40	12.90	12.80	35.60	60.00	31.20	
14:02	7.80	79.90	56.70	89.60	7.80	14.40	13.10	13.80	35.10	60.00	31.30	
15:02	6.80	79.90	58.80	79.40	6.80	13.90	12.10	10.80	28.50	75.00	28.30	
16:02	6.80	78.80	58.80	74.70	6.80	13.90	12.10	10.80	27.50	80.00	26.30	
17:02	6.80	75.80	56.80	75.50	6.80	13.40	11.70	10.80	27.00	80.00	25.30	
18:02	6.80	76.80	55.70	72.30	6.80	13.90	11.90	10.80	27.00	80.00	25.80	
19:02	6.80	73.80	56.80	72.60	6.80	13.40	11.90	10.80	28.00	75.00	26.30	
20:02	6.80	74.90	57.30	71.10	6.80	13.40	11.90	10.80	28.50	75.00	26.30	
21:02	6.80	76.10	53.80	70.60	6.80	13.40	11.90	10.80	30.00	70.00	26.80	
22:02	6.80	74.90	57.60	67.70	6.80	13.40	11.70	10.80	29.50	70.00	26.80	
23:02	6.80	73.70	57.00	70.00	6.80	13.40	11.70	10.80	29.00	65.00	26.00	

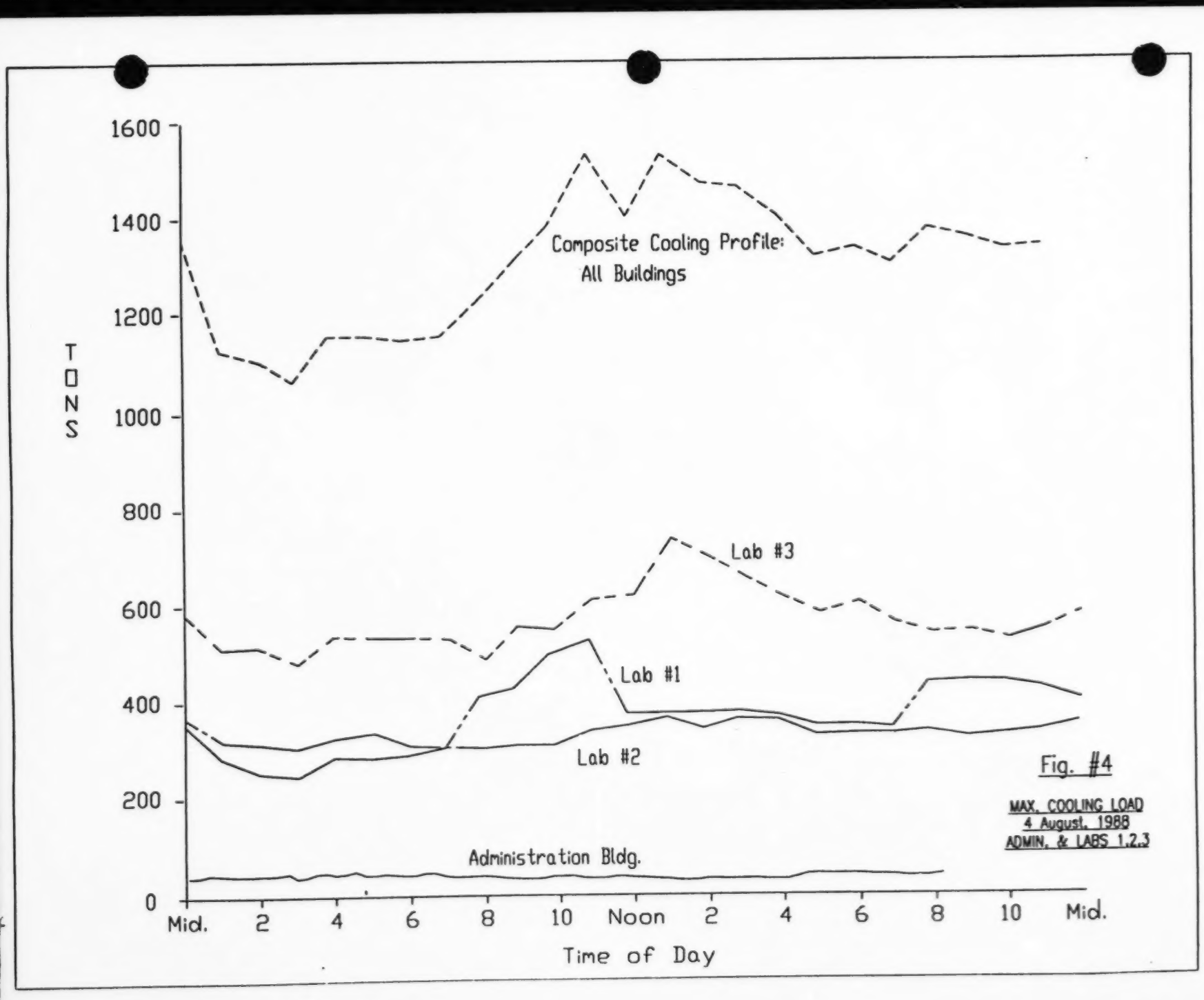


Fig. #4

MAX. COOLING LOAD
4 August, 1988
ADMIN. & LABS 1,2,3

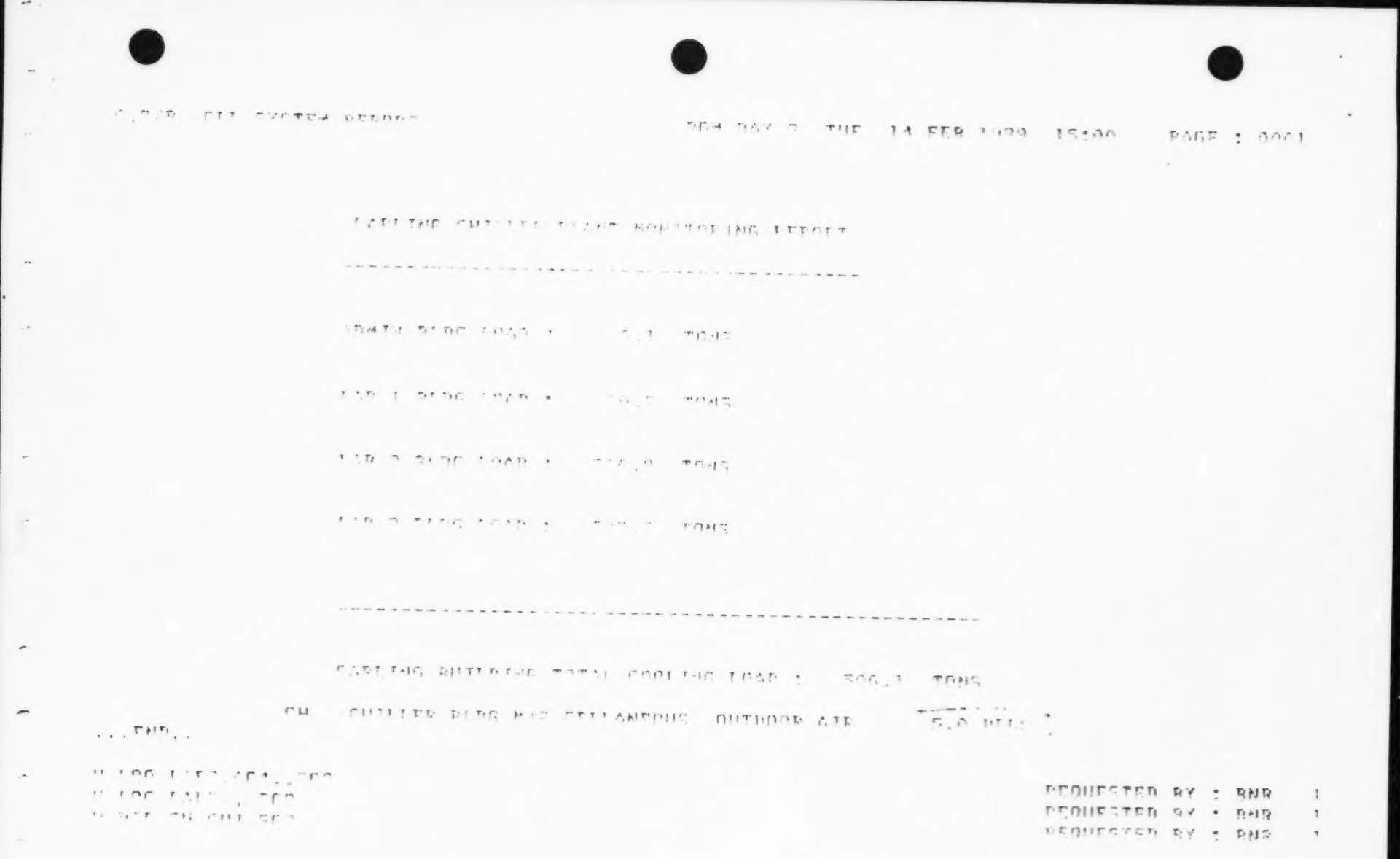


Figure #5

HEAVIEST WINTER COOLING LOAD

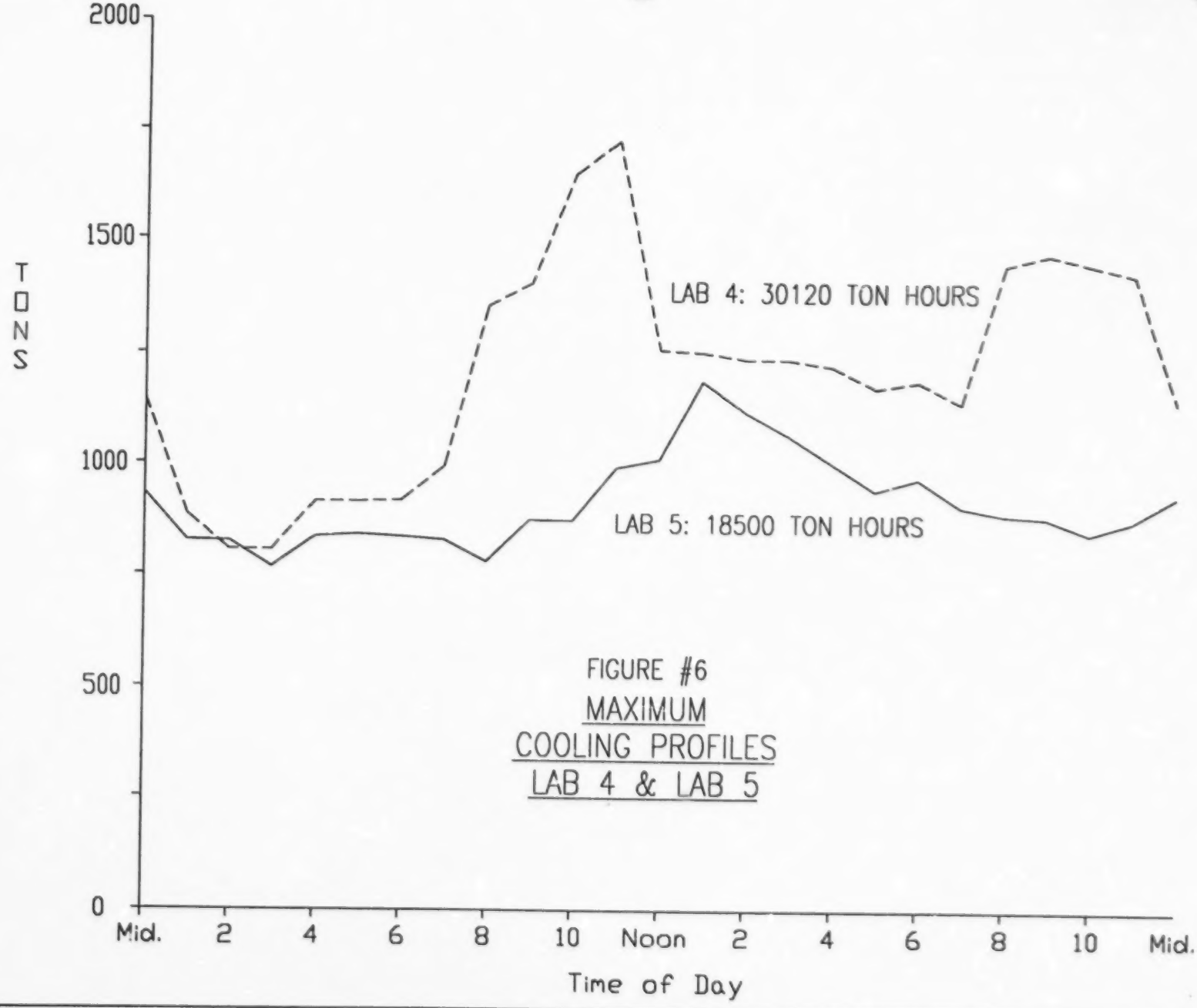


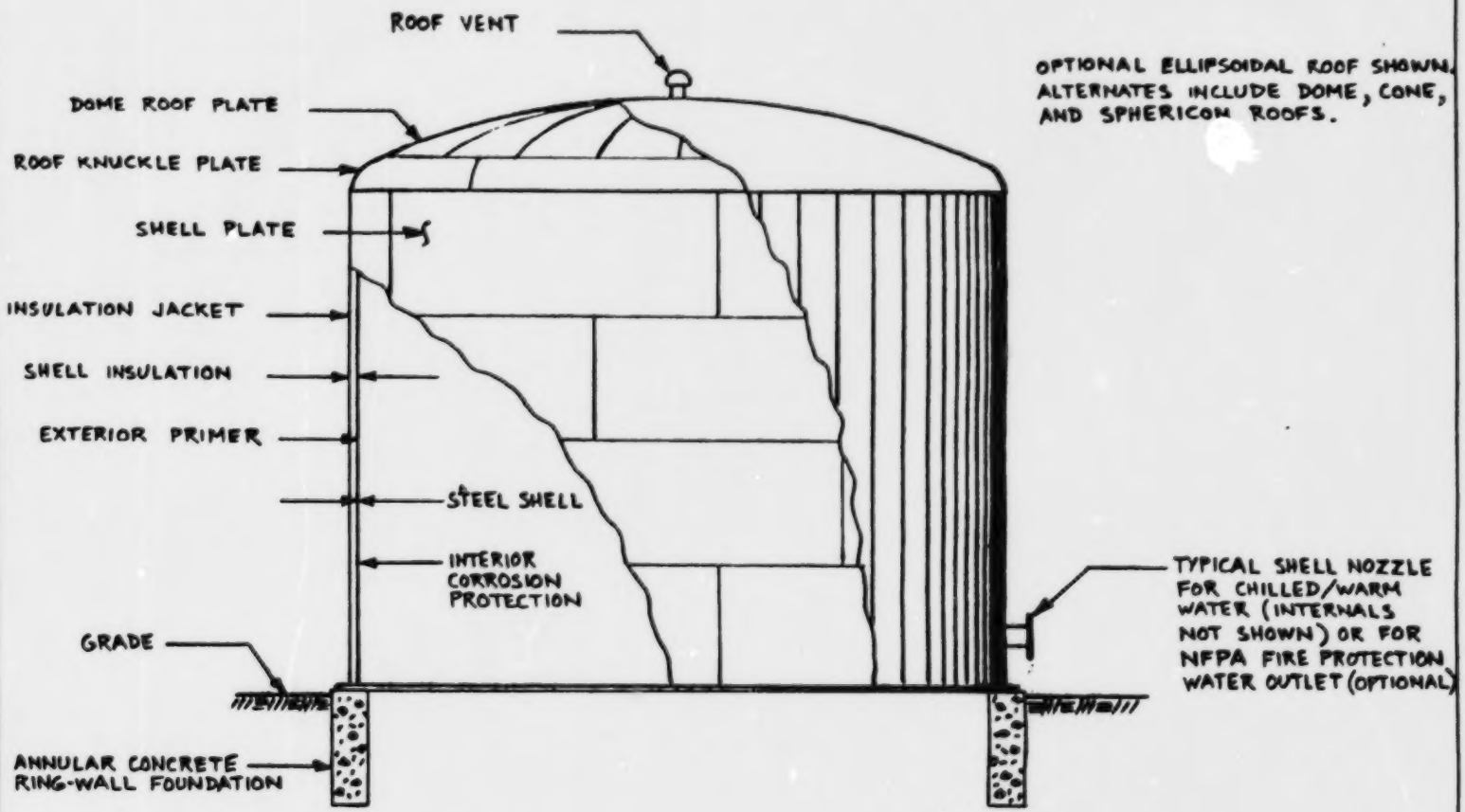
FIGURE #6

MAXIMUM

COOLING PROFILES

LAB 4 & LAB 5

TYPICAL STRATA-THERM CHILLED WATER THERMAL ENERGY STORAGE INSTALLATION


ROOF VENT
DOME ROOF PLATE
ROOF KNUCKLE PLATE
SHELL PLATE
INSULATION JACKET
SHELL INSULATION
EXTERIOR PRIMER
STEEL SHELL
INTERIOR CORROSION PROTECTION
GRADE
ANNULAR CONCRETE RING-WALL FOUNDATION
OPTIONAL ELLIPSOIDAL ROOF SHOWN. ALTERNATES INCLUDE DOME, CONE, AND SPHERICON ROOFS.
TYPICAL SHELL NOZZLE FOR CHILLED/WARM WATER (INTERNALS NOT SHOWN) OR FOR NFPA FIRE PROTECTION WATER OUTLET (OPTIONAL)

SUBJECT: Typical Strata-Therm Chilled Water TES Installation

OFFICE: NEW

MADE BY: JSA DATE: 2/8/84

CHKD BY: DATE:

REVISION: MADE BY: DATE: CHKD BY: DATE:

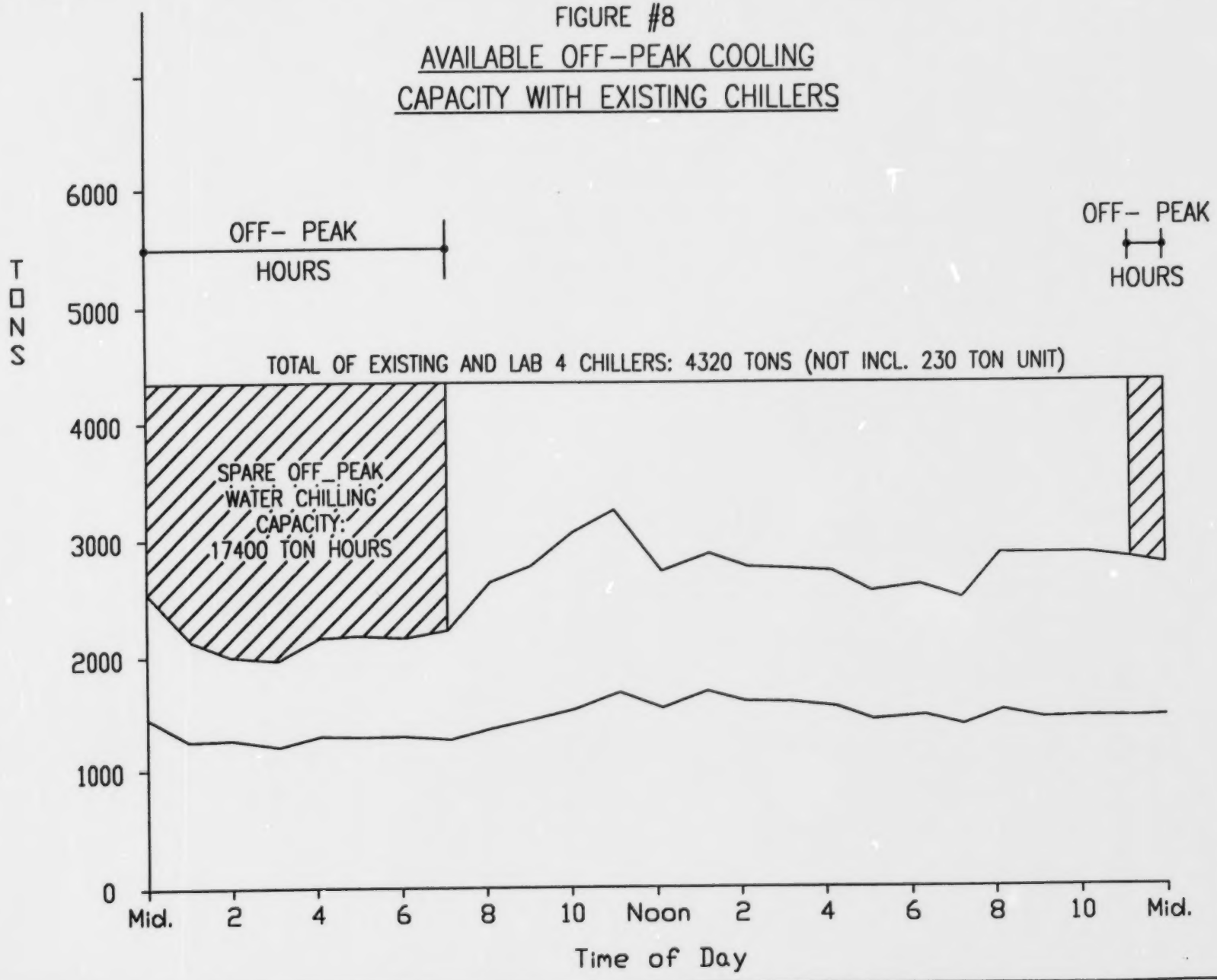
REFERENCE NO.

SHT. ___ OF ___

Figure 7

FIGURE #8

AVAILABLE OFF-PEAK COOLING CAPACITY WITH EXISTING CHILLERS



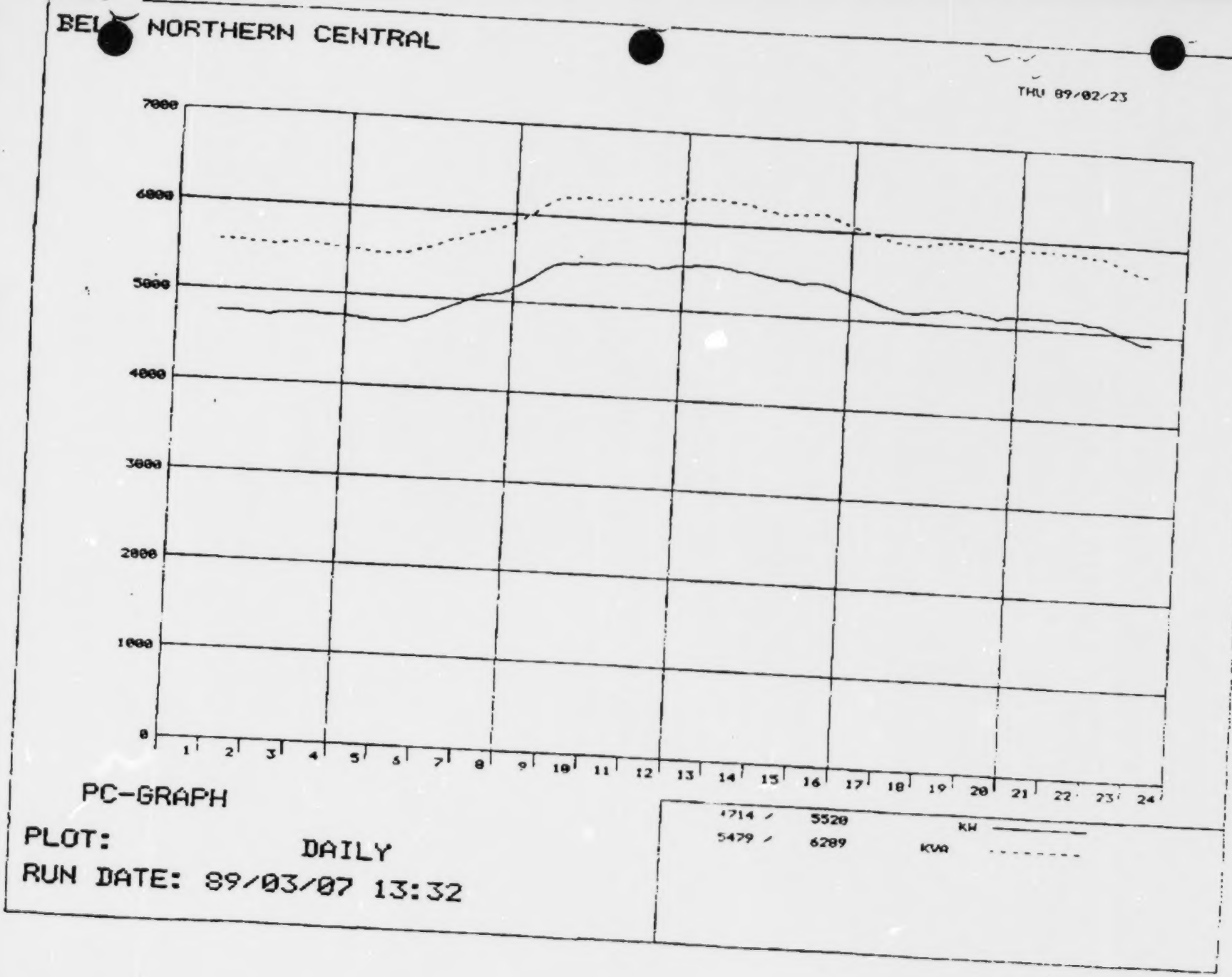
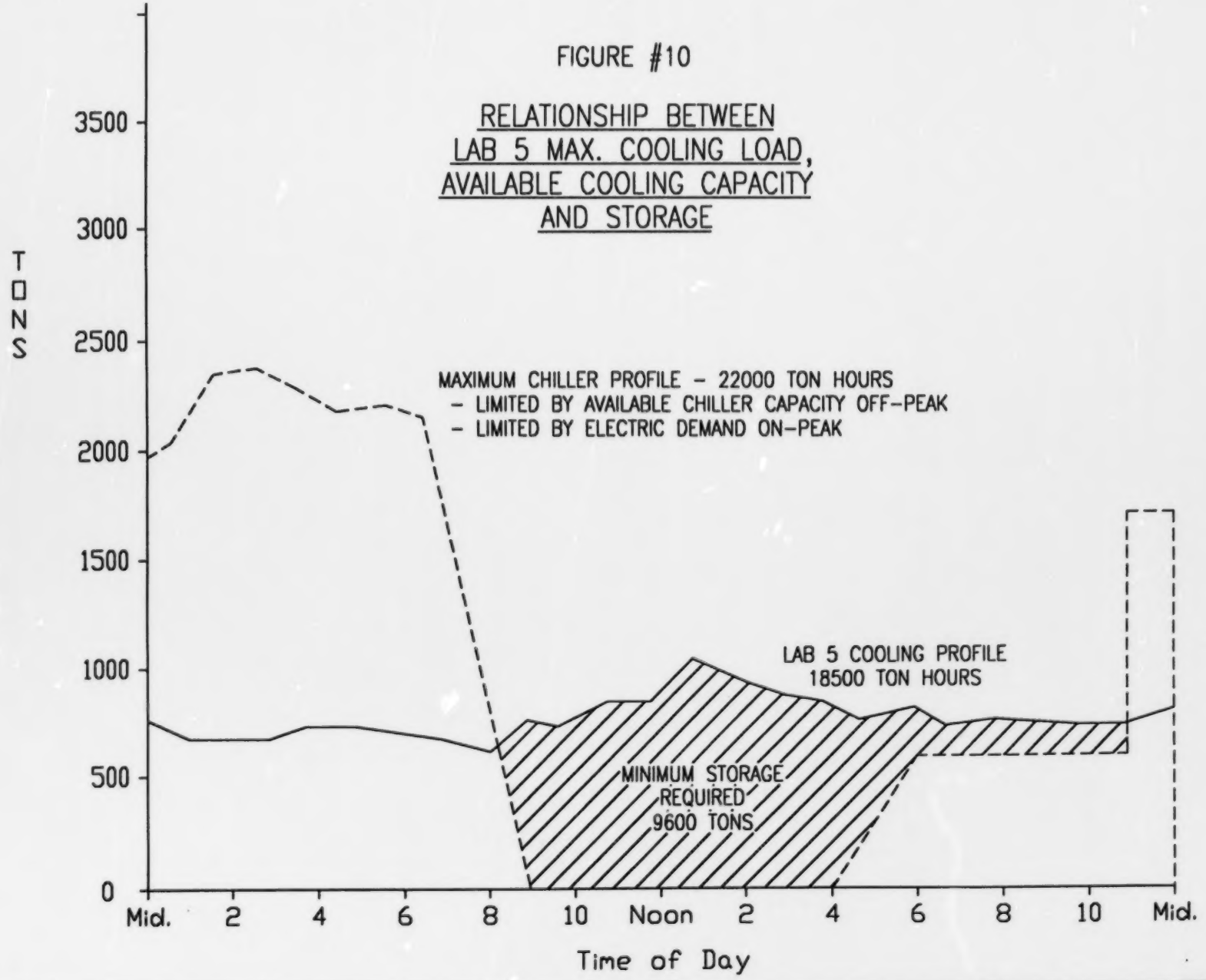

BEL NORTHERN CENTRAL
THU 89/02/23
7000
6000
5000
4000
3000
2000
1000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
PC-GRAPH
PLOT: DAILY
RUN DATE: 89/03/07 13:32
4714 / 5520
5479 / 6289
KW
KVA

Figure 9

FIGURE #10

RELATIONSHIP BETWEEN LAB 5 MAX. COOLING LOAD, AVAILABLE COOLING CAPACITY AND STORAGE



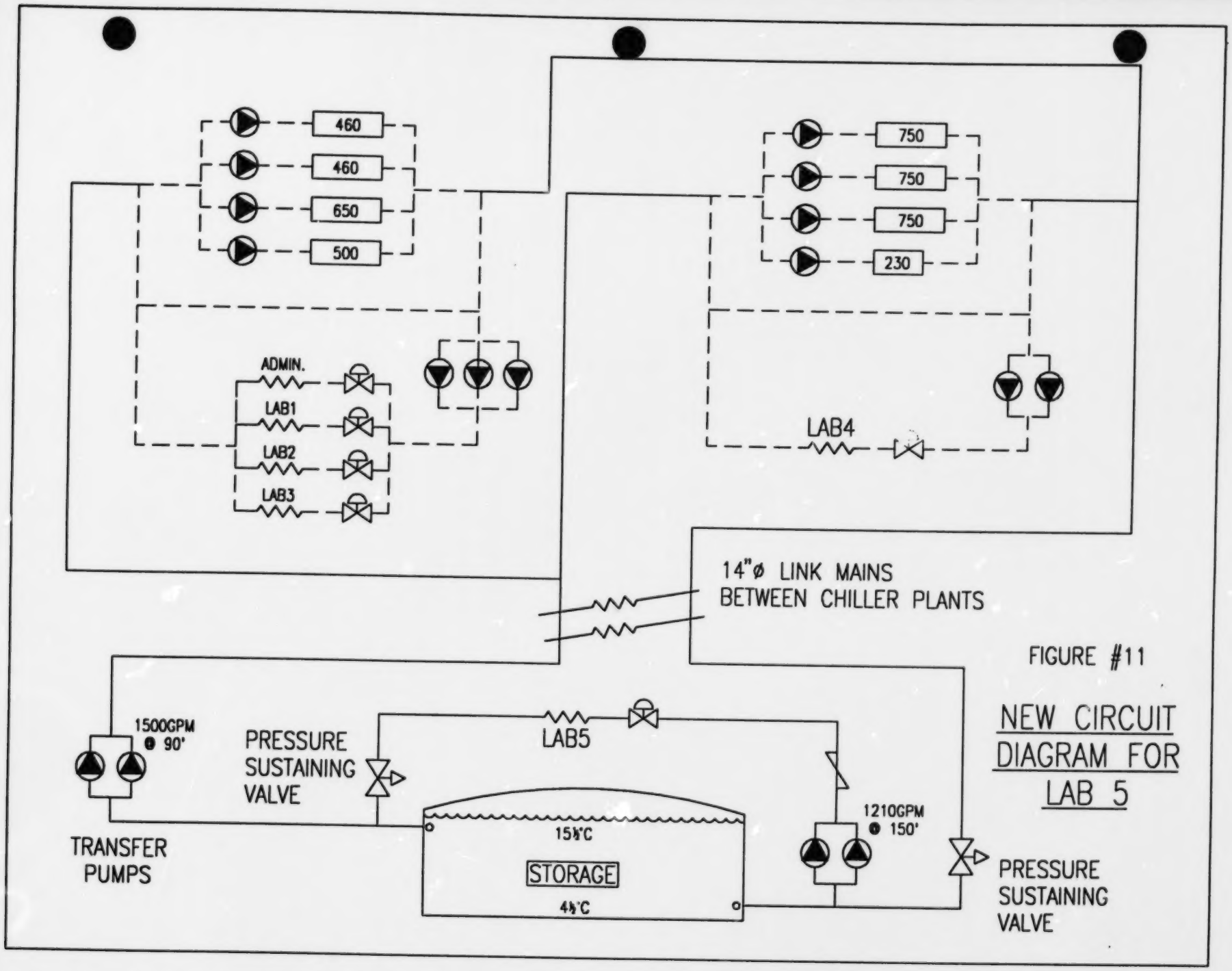


FIGURE #11

NEW CIRCUIT DIAGRAM FOR LAB 5

FIGURE #12

LEVEL LOAD COOLING DIAGRAM
BELL NORTHERN RESEARCH
LAB 5

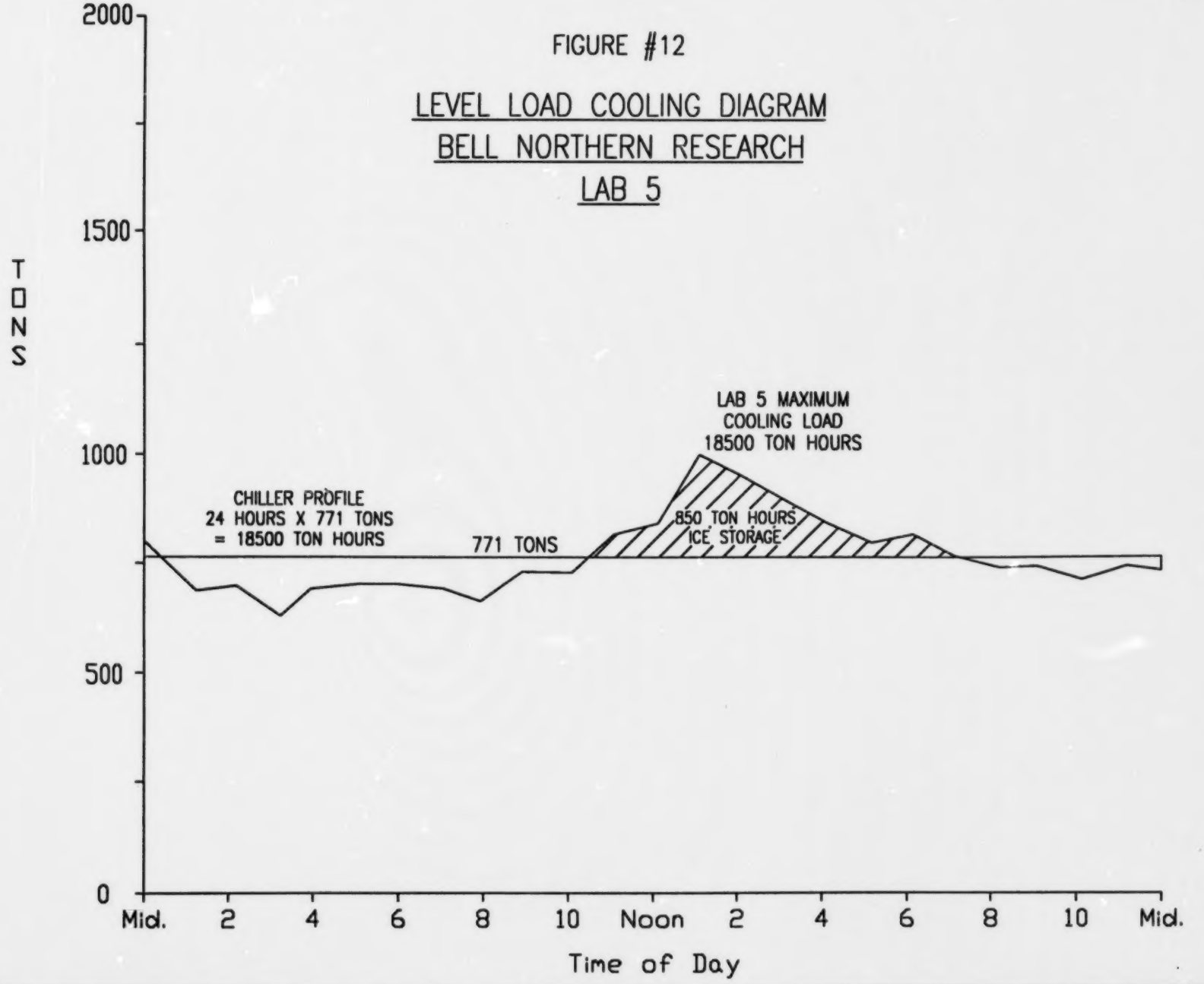
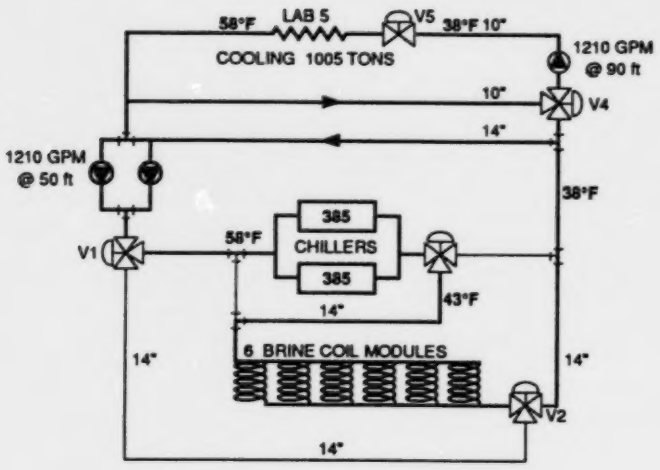
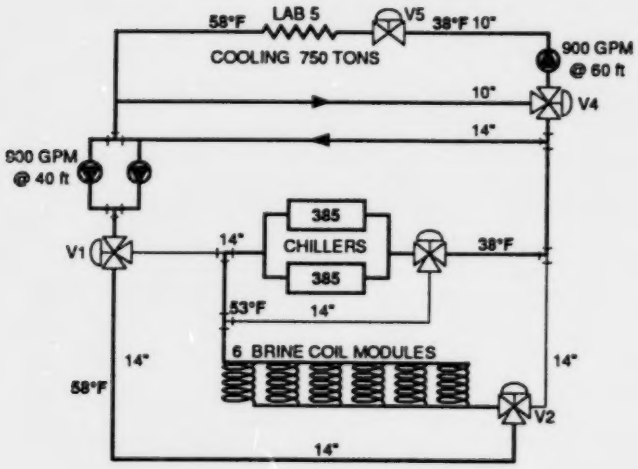


Figure 13

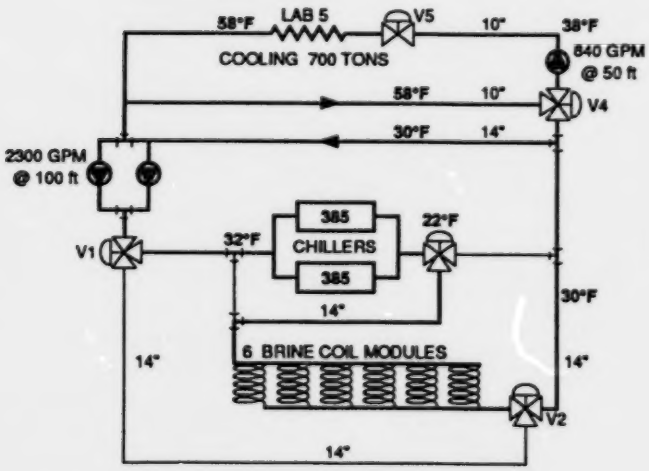
Brine Coil Circuitry



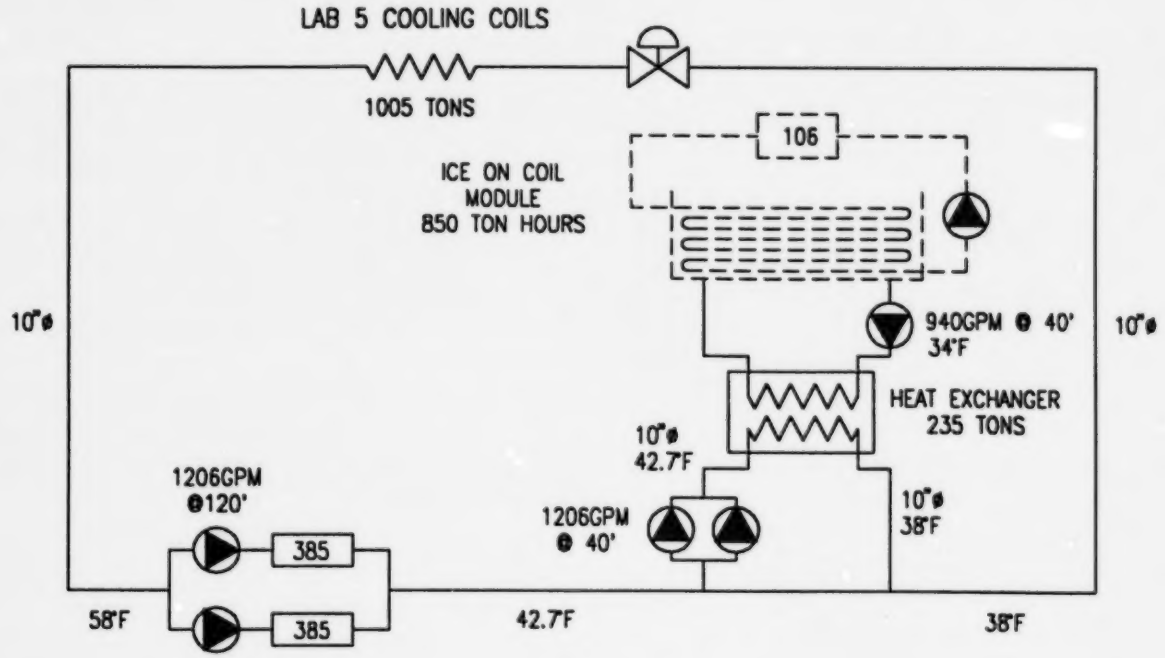
DAY - STORAGE
DISCHARGE CYCLE



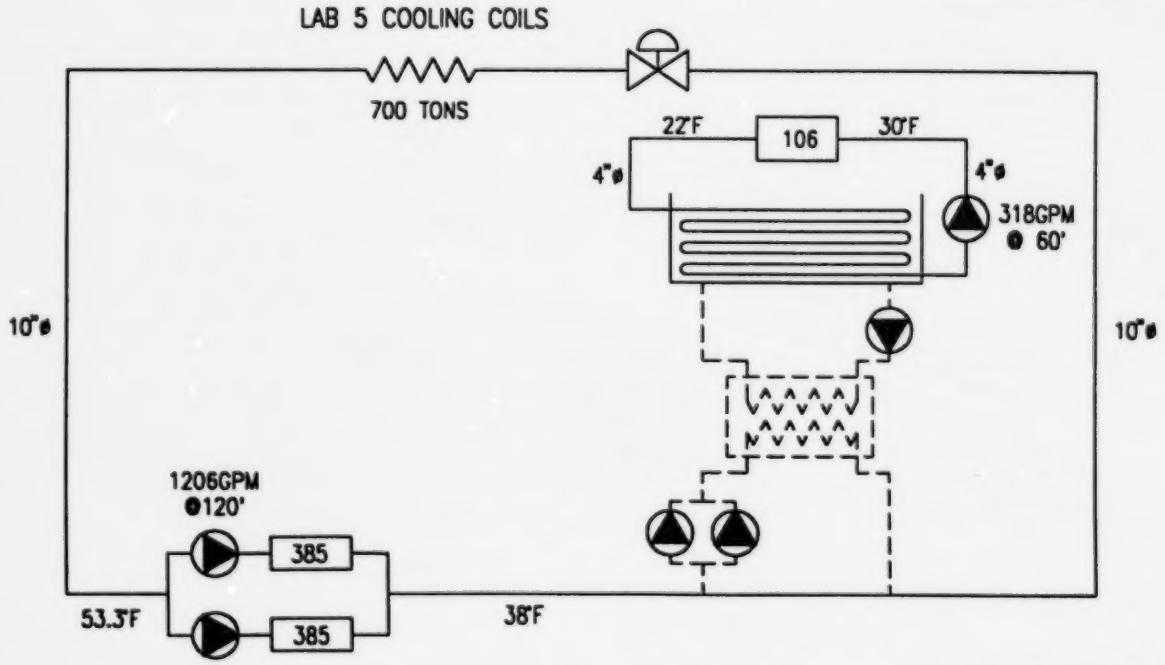
EVENING - STORAGE
DISCHARGE CYCLE



NIGHT - STORAGE
REGENERATION CYCLE



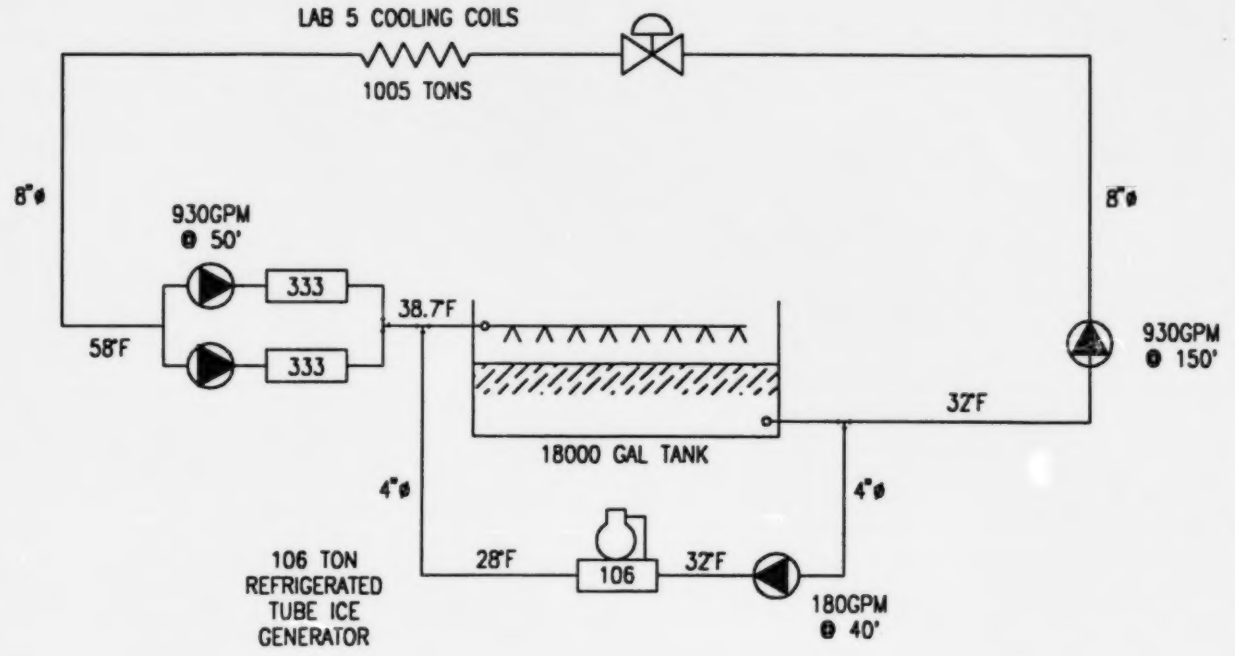
7AM - 11PM



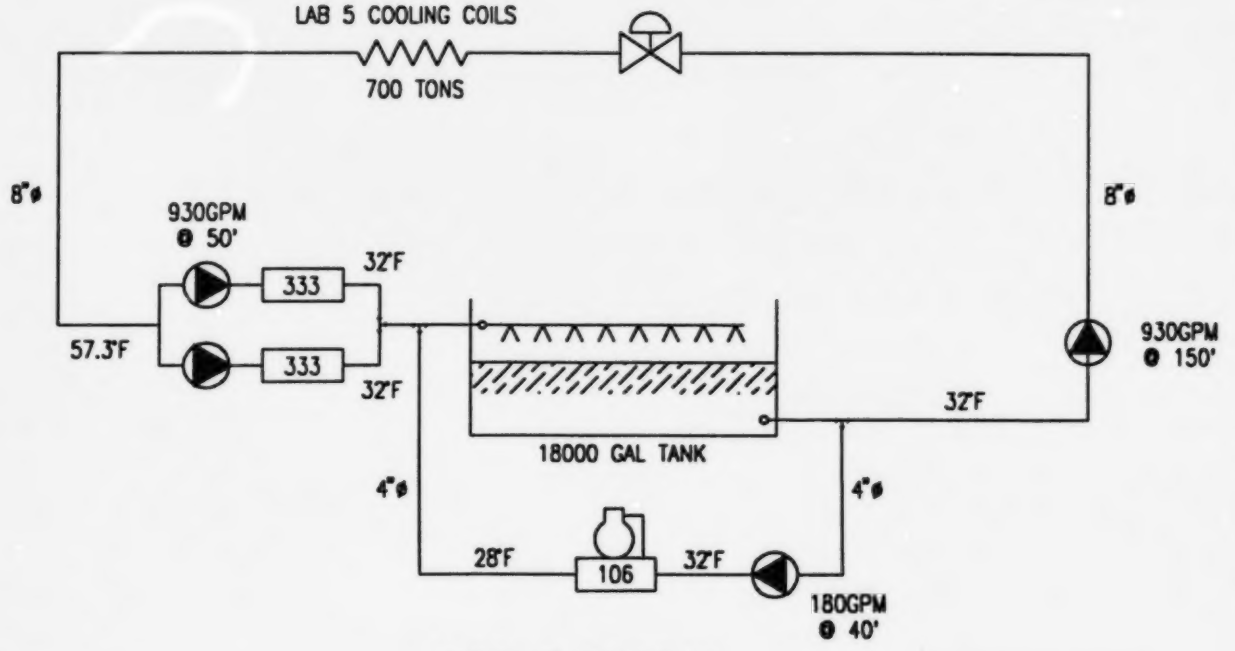
11PM - 7AM

ICE ON COIL CIRCUITRY

FIGURE 14



7AM – 11PM



11PM – 7AM

CIRCUIT DIAGRAM
FOR
REFRIGERATED TUBE

FIGURE 15

Figure 16

Chilled Water Storage for Lab 5

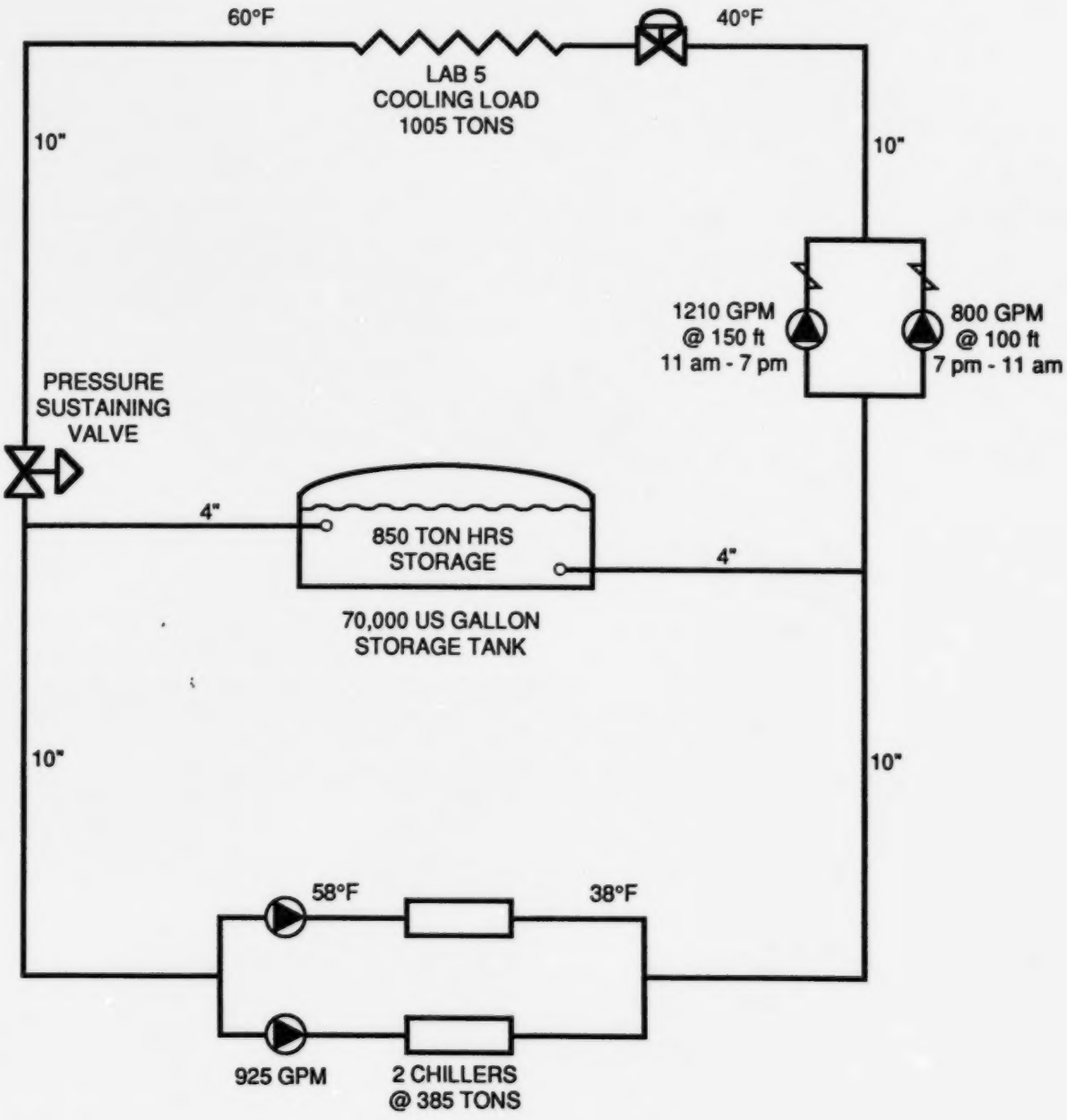


FIGURE 17

INITIAL COST COMPARISON

Item	Conventional (No Storage) $	Brine Coil $	Ice on Coil $	Refrigerated Tube $	Chilled Water New Chillers $	Chilled Water Existing Chillers $
Chiller #1 Centrifugal	111,000 (500 tons @ 42F)	133,000 (385 tons @ 22F)	103,000 (385 tons @ 38F)	117,000 (333 tons @ 32F)	103,000 (385 tons @ 38F)	-
Chiller #2 Centrifugal	111,000 (500 tons @ 42F)	133,000 (385 ton @ 22F)	103,000 (385 tons @ 38F)	117,000 (333 tons @ 32F)	103,000 (385 tons @ 38F)	-
Chiller #3 Screw or Reciprocating	-	-	55,000 (106 tons @ 22F)	Included in ice module cost	-	-
Water Tower @ $72/ton	75,000	55,000	55,000	55,000	55,000	-
Condensing Water Pumps @ $10/GPM, 3 GPM/ton	30,000	23,000	23,000	23,000	23,000	-
Cooling Coil Pumps @ $10/GPM	12,000	12,000	12,000	9,500	12,000	12,000
Chiller Pumps @ $10/GPM	-	12,000	-	9,500	9,500	-
Heat X Pumps @ $10/GPM	-	-	12,000	-	-	-
Storage Pumps @ $10/GPM	-	-	9,500	-	-	-
Transfer Pumps @ $10/GPM	-	-	-	-	-	15,000
Bases/Rigging for above	10,000	10,000	10,000	10,000	10,000	2,000
Glycol @ $10/gal	-	15,000 (5000 gal @ 30%)	3,000 (1000 gal @ 30%)	12,000 (23,000 gal @ 5%)	-	-

FIGURE 17 (CONTD)

INITIAL COST COMPARISON

Item	Conventional (No Storage) $	Brine Coil $	Ice on Coil $	Refrigerated Tube $	Chilled Water New Chillers $	Chilled Water Existing Chillers $
Heat Exchanger	-	-	20,000	-	-	-
Ice Modules	-	98,000 (6 units 850 ton hrs)	66,000 (1 unit 850 ton hrs)	156,000 (incl 106 ton compressor)	-	-
Ice Tank @ 1.25/gal	-	-	-	23,000 (850 ton hrs)	-	-
Start up Supervision for Ice	-	25,000	25,000	25,000	-	-
Interface Piping	-	25,000	25,000	25,000	25,000	25,000
Automated Valves	-	30,000	-	-	10,000	10,000
System Interconnection 2000 ft 14" pipe @ $10/ft.inch	-	-	-	-	-	280,000
Chilled Water Storage Tank	-	-	-	-	80,000 (70,000 gals)	450,000 (1,000,000 gals)
Water Treatment Packages	25,000	25,000	25,000	30,000	30,000	50,000
Equipment Space @ $50/SF	100,000	100,000	100,000	100,000	100,000	20,000
Sub Total	**474,000**	**684,000**	**646,500**	**722,000**	**570,500**	**864,000**

FIGURE 17 (CONTD)

INITIAL COST COMPARISON

Item	Conventional (No Storage) $	Brine Coil $	Ice on Coil $	Refrigerated Tube $	Chilled Water New Chillers $	Chilled Water Existing Chillers $
Markups 10% + 5%	73,000	106,000	100,000	112,000	88,000	134,000
Contingency 10%	47,000	68,000	65,000	72,000	57,000	86,000
Engineering Fee 5%	25,000	34,000	33,000	30,000	29,000	43,000
TOTAL	**619,000**	**892,000**	**845,000**	**942,000**	**745,000**	**1,127,000**
Hydro Grant @ $200/kW avoided	-	44,000	39,000	26,000	36,000	189,000
NET COST	**619,000**	**848,000**	**806,000**	**916,000**	**709,000**	**938,000**

FIGURE 18

KW INPUT TO COOLING PLANT FOR VARIOUS STORAGE SCHEMES

Item	Conventional No Storage	Brine Coil	Ice on Coil	Refrigerated Tube	Chilled Water New Chillers	Chilled Water Existing Chillers
DAY						
New Chiller #1	350	270	270	250	280	-
New Chiller #2	350	270	270	250	280	-
New Chiller #3	-	-	-	120	-	-
Existing Chillers	-	-	-	-	-	-
Tower Pumps	160	120	120	120	120	-
Tower Fans	90	70	70	70	70	-
Cooling Coil Pumps	45	30	45	40	50	50
Chiller Pumps	-	15	-	15	15	-
Heat Exchanger Pumps	-	-	15	-	-	-
Storage Pumps	-	-	10	2	-	-
Transfer Pumps	-	-	-	-	-	-
Air Compressor	-	-	-	-	-	-
TOTAL	995	775	800	867	815	50
NIGHT						
New Chiller #1	250	370	290	280	280	-
New Chiller #2	250	370	290	280	280	-
New Chiller #3	-	-	140	120	-	-
Existing Chillers	-	-	-	-	-	840
Tower Pumps	160	120	120	120	120	175
Tower Fans	90	70	70	70	70	125
Cooling Coil Pumps	45	15	45	40	35	35
Chiller Pumps	-	65	-	15	15	15
Heat Exchanger Pumps	-	-	-	-	-	-
Storage Pumps	-	-	-	2	-	-
Transfer Pumps	-	-	-	-	-	-
Air Compressor	-	-	2	-	-	35
TOTAL	795	1010	957	927	800	1235

FIGURE 19

DEVELOPMENT OF AN APPROXIMATE ANNUAL COST OF COOLING

Storage System	kWh Energy		$ Energy		$ TOTALS				
	Day	Month (22 full load days)	7 am-11 pm @ 2.79¢/kWh	11 pm-7 am @ 1.86¢/kWh	Total	kW Demand	Demand @ $9.33/kW	Month	(7 full load months)
Conventional (No Storage)									
Day	15,920	350,240	9,772						
Night	6,360	139,920		2,603					
Total	22,280	490,160			12,375	995	9,283	21,658	151,603
Brine Coil									
Day	12,400	272,800	7,611						
Night	8,080	177,760		3,306					
Total	20,480	450,560			10,917	775	7,231	18,148	127,036
Ice on Coil									
Day	12,800	281,600	7,857						
Night	7,656	168,432		3,133					
Total	20,456	450,032			10,990	800	7,464	18,454	129,178
Refrigerated Tube									
Day	13,872	305,184	8,515						
Night	7,416	163,152		3,035					
Total	21,288	468,336			11,550	867	8,089	19,639	137,473
Chilled Water (New Chillers)									
Day	13,040	286,880	8,004						
Night	6,400	140,800		2,619					
Total	19,440	427,680			10,623	815	7,604	18,227	127,589
Chilled Water Existing Chillers									
Day	800	17,600	491						
Night	9,880	217,360		4,043					
Total	10,680	234,960			4,534	50	467	5,001	35,007

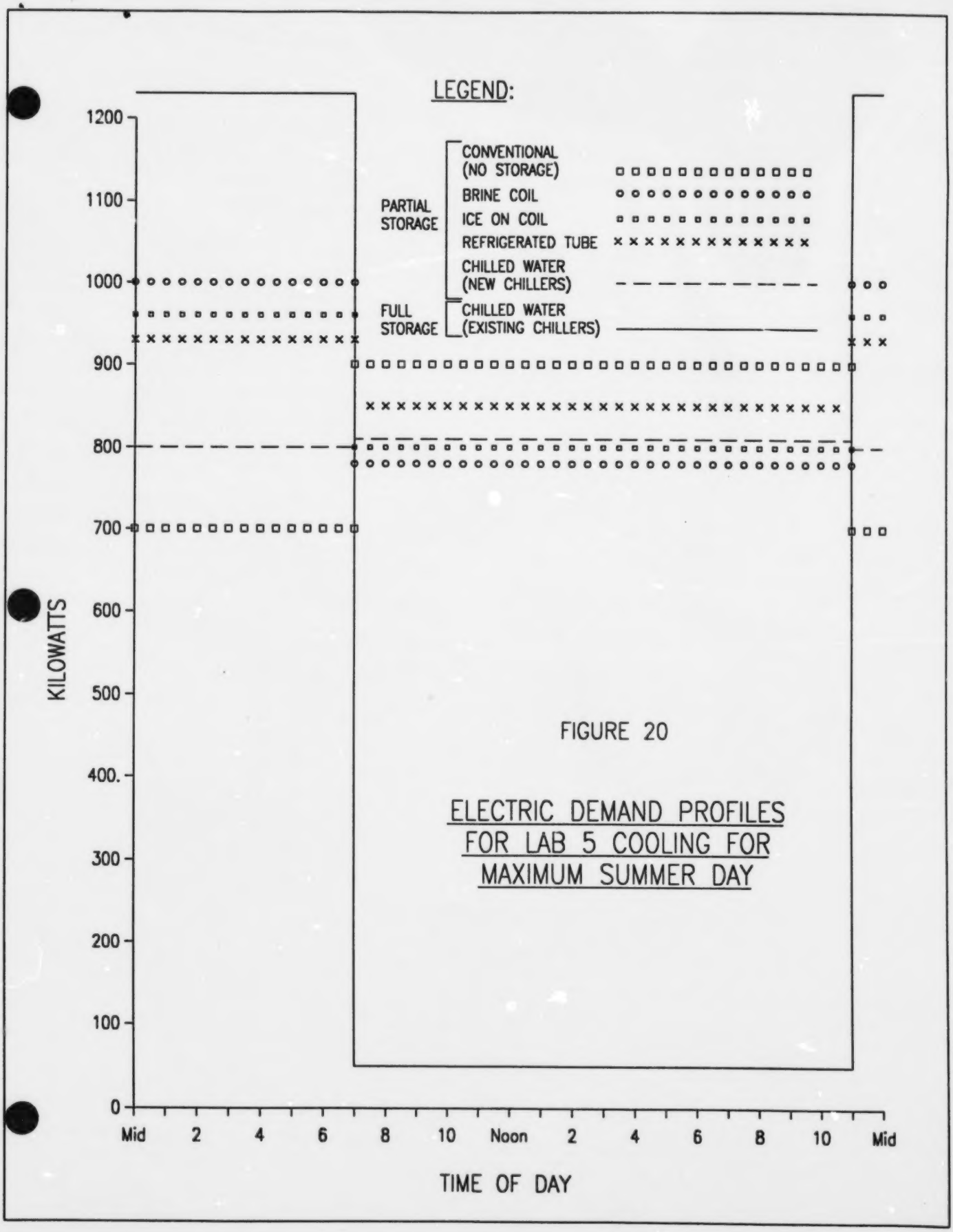


FIGURE 20

ELECTRIC DEMAND PROFILES FOR LAB 5 COOLING FOR MAXIMUM SUMMER DAY

FIGURE 21

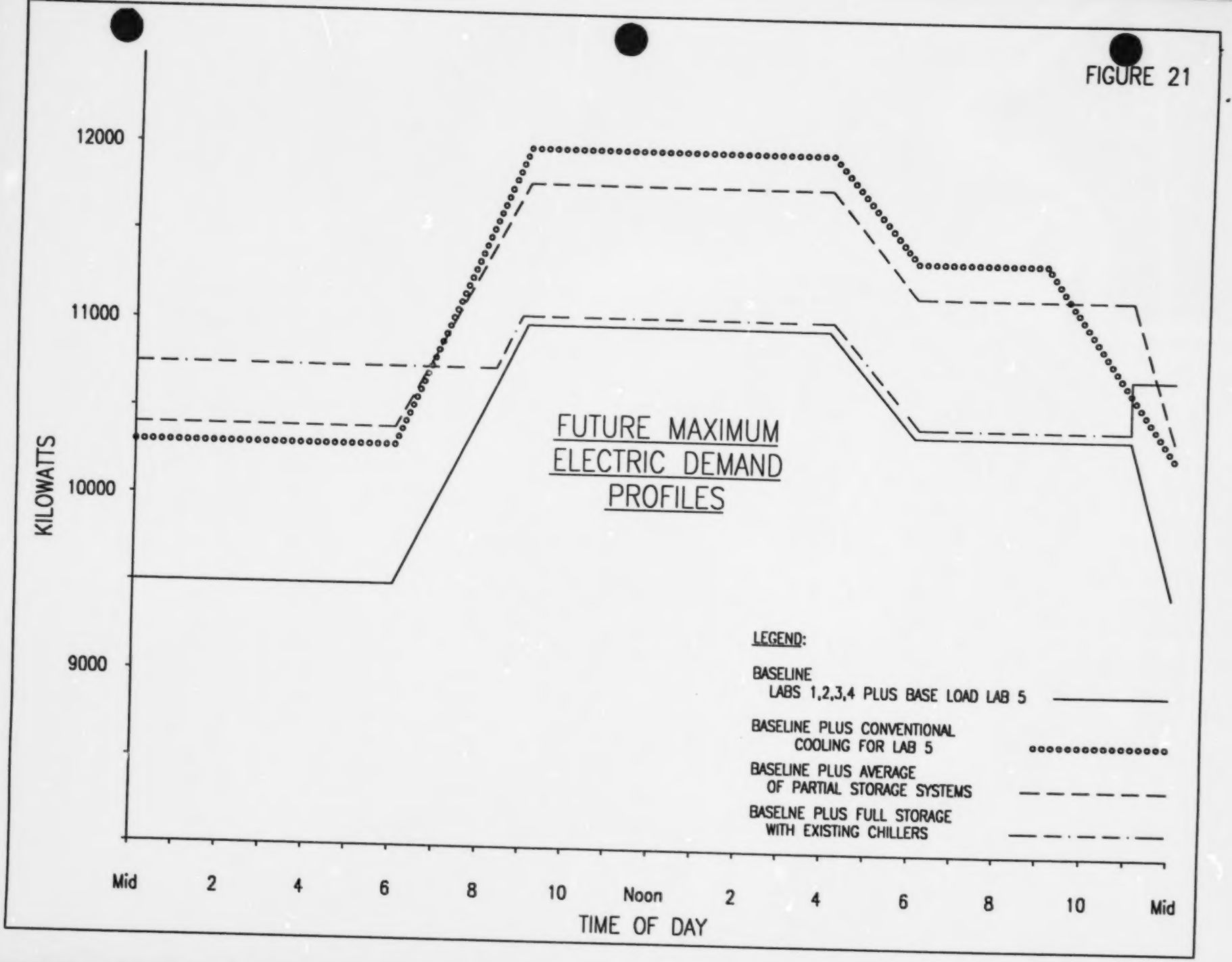

12000
11000
10000
9000
KILOWATTS
FUTURE MAXIMUM
ELECTRIC DEMAND
PROFILES
LEGEND:
BASELINE
LABS 1,2,3,4 PLUS BASE LOAD LAB 5
BASELINE PLUS CONVENTIONAL
COOLING FOR LAB 5
BASELINE PLUS AVERAGE
OF PARTIAL STORAGE SYSTEMS
BASELNE PLUS FULL STORAGE
WITH EXISTING CHILLERS
Mid
2
4
6
8
10
Noon
2
4
6
8
10
Mid
TIME OF DAY

FIGURE 22

COMPARISON OF SYSTEMS AFTER FIVE YEARS OF ENERGY COST

Item	Conventional No Storage $	Brine Coil $	Ice on Coil $	Refrigerated Tube $	Water Storage New Chillers $	Water Storage Existing Chillers $
First Cost from Figure 17	619,000	848,000	806.000	916,000	709,000	938,000
Approx. Annual Cost of Cooling from Figure 18	151,603	127,036	129,178	137,473	127,589	35,007
Annual Saving for Storage Systems	-	24,567	22,425	14,130	24,014	116,596
Saving for Five Years	-	122,835	112,125	70,650	120,070	582,980
First Cost Less Five Years Savings	619,000	725,165	693,875	845,350	588,930	355,020